Breeding Field Crops

Third Edition

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Preface

While preparing the first edition of this textbook I attended an extension short course on writing agricultural publications. The message I remember was "select your audience and write to it." There has never been any doubt about the audience for which this textbook was written, the introductory course in crop breeding. In addition, it has become a widely used reference for the graduate plant-breeding student and the practicing plant breeder. In its preparation, particular attention has been given to advances in plant-breeding theory and their utility in plant-breeding practice. The blend of the theoretical with the practical has set this book apart from other plant-breeding textbooks.

The basic structure and the objectives of the earlier editions remain unchanged. These objectives are (1) to review essential features of plant reproduction, Mendelian genetic principles, and related genetic developments applicable in plant-breeding practice; (2) to describe and evaluate established and new plant-breeding procedures and techniques, and (3) to discuss plant-breeding objectives with emphasis on the importance of proper choice of objective for achieving success in variety development. Because plant-breeding activities are normally organized around specific crops, there are chapters describing breeding procedures and objectives for the major crop plants; the crops were chosen for their economic importance or diversity in breeding systems. These chapters provide a broad overview of the kinds of problems with which the breeder must cope. Since textbook examples can not be inclusive of all breeding situations, the breeders are urged to develop procedures and choose the objectives that fit their particular situation. Extensive bibliographies are included with each chapter.

In this third edition, new chapters have been added on quantitative genetics, hybrid breeding, and plant cell and tissue culture to fill some gaps in earlier editions and to introduce new technology. The purpose of the chapter on tissue culture is to present the kinds of procedures that have potential utility for the plant breeder. Literature in this field is extensive, sometimes contradictory, or without focus on practical plant-breeding application. The intensive research going forward in the field should clarify the practical applications with time and experience. Other chapters have been revised, some extensively. Procedures for breeding self-pollinated crops have been updated, with accelerated selection schedules that are more in line with current breeding practice; procedures for breeding cross-pollinated crops have been expanded and clarified. Although *cultivar* is the preferred term in scientific literature, *variety* is still the term of the farmer and the seed producers in the United States and is used here.

My sincere thanks are expressed to all who have assisted in making this book possible. I am indebted to the following for reading one or more chapters and offering useful suggestions: T. C. Barker, G. Benzion, H. L. Carnahan, G. B. Collins, W. Crook, C. V. Feaster, M. S. Khan, P. A. Lazzeri, J. Meyers, R. K. Oldemeyer, W. M. Ross, J. P. Thomas, S. T. Tseng, E. L. Turcotte, G. A. White, and M. H. Yu. Many of my colleagues at the University of Missouri, Columbia, have given freely of their time and counsel, but special acknowledgment is due to W. E. Aslin, P. R. Beuselinck, L. E. Cavanah, E. H. Coe, Jr., C. Dai, L. L. Darrah, G. F. Krause, D. Mertz, M. G. Neuffer, S. G. Pueppke, G. P. Rèdei, W. P. Sappenfield, E. R. Sears, D. A. Sleper, and M. S. Zuber. However, I assume full responsibility for the writing and hope that errors or misstatements will be called to my attention for correction.

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1

Plant Breeders and Their Work

Production of food is a problem of major concern in the world today. The world's food supply, grossly inadequate in many countries today, will need to be increased greatly in the years ahead if the basic nutritional requirements of an explosive world population are to be satisfied (Fig. 1.1). Otherwise, the specter of hunger, malnutrition, and famine, already a reality with two-thirds of the world's people, will continue to spread and grow, and the nutritional gap between the developed and the underdeveloped countries will continue to widen.

Field crops provide the principal source of the world's food supply. Over 50% of the human food consumed comes directly from seven cereal grains; over 40% comes from rice and wheat (Fig. 1.2). Other foods of vegetable origin include the root crops, oilseeds, vegetables, fruits, and nuts. Forage and grain crops utilized as livestock feed may be consumed indirectly as meat, milk, or eggs.

Field crops, in addition to their production for human food and livestock feed, are utilized for fiber, fuel, plastics, stimulants, and many other commercial uses. For these purposes we grow crops like cotton, jute, fiber flax, tobacco, soybeans, linseed flax, and corn. The potential for utilizing plants as sources of energy has been little exploited. When this happens the production of food may be placed further in jeopardy.

To increase crop production, four important inputs need major attention: *water, fertilizer, pest control,* and *crop variety*. The first three—water, fertilizer, and pest control—relate to cultural practices that provide a more desirable environment in which to grow the crop. The fourth—the crop variety—relates to the inherent ability of the plant to produce within the environment provided. In other words, more productive plants and greater food production may result both by improving the environment for crop growth and by improving the heredity of the crop. Improving the heredity of a crop, stated most

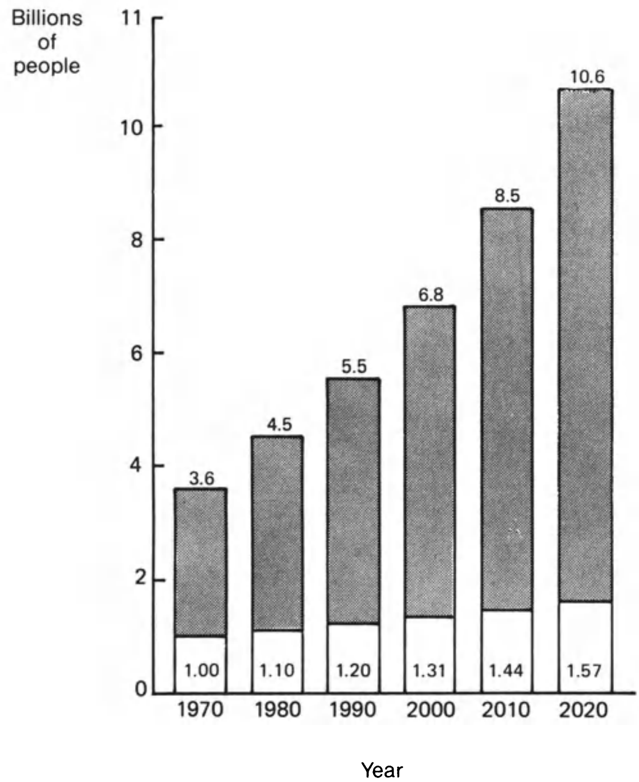

FIG. 1.1. Increase in world population in developed (unshaded) and underdeveloped (shaded) countries projected to year 2020.

simply, is accomplished by *breeding* better varieties. It is this aspect of increasing crop production that is given consideration in this text.

Hereditary improvements in crop varieties are made in various ways. The improved variety may be more vigorous in its growth, thus producing a higher yield through the more efficient use of the sunlight, carbon dioxide, water, and plant nutrients available to it. Its structure may be altered so that it will stand until harvest with less loss from lodging or shattering. Plants may be selected with more tolerance to stress, so that a satisfactory yield will be harvested when environmental conditions over which the grower has no control are unfavorable. To accomplish this objective the breeder strives for early maturity, increased winter hardiness, or resistance to heat, drought, disease, and insect damage. Cultural practices to increase yield—fertilization, irrigation, application of chemicals for pest control—must be repeated with each new cropping season. Hereditary improvements are more or less permanent; by planting improved varieties, the benefits may be reaped over and over.

Maximum crop production cannot be achieved either by use of superior cultural practices or by planting improved varieties alone. Without good production practices the high yield potential of a superior variety would be

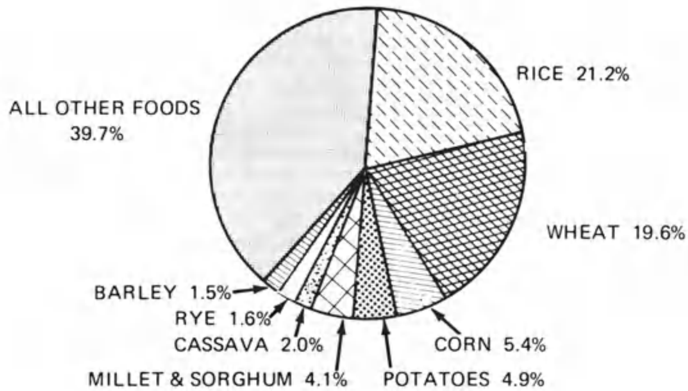

FIG. 1.2. Source of food used by the world's people. Over 50% of the food supply comes from seven cereal grains, over 40% from rice and wheat.

largely wasted. Neither will maximum benefits be realized from good production practices unless a potentially high yielding variety is grown.

In the United States, the combination of improved varieties and superior cultural practices resulted in significantly higher yields of the major field crops during the 50-year period 1931–1980 (Fig. 1.3). Most spectacular are the hectare increases from the 1931–1935 to the 1976–1980 period in the yields of corn (325%) and sorghum (320%). It was during this 50-year period that pro-

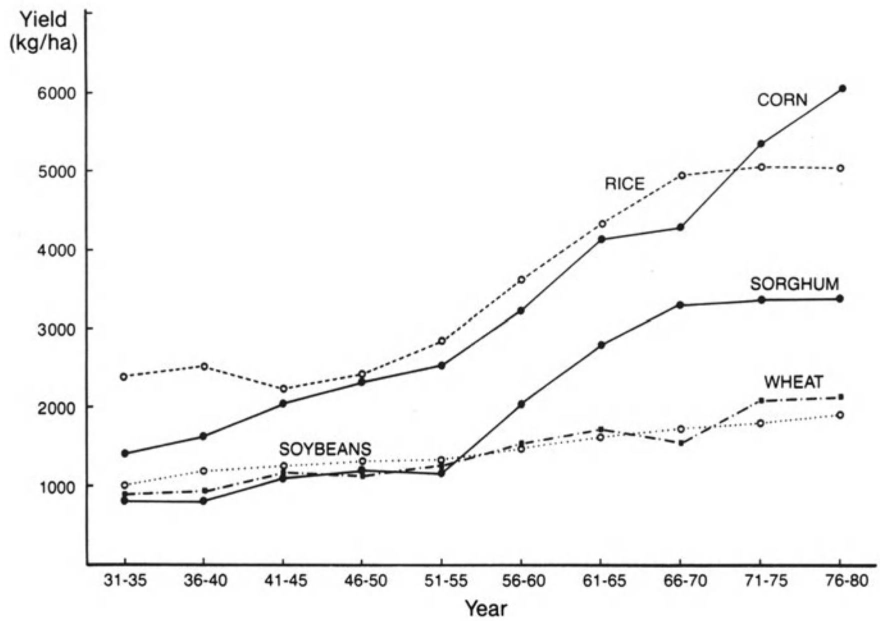

FIG. 1.3. Yields of major field crops in the United States, 1931–1980. During the 50-year period, yields of corn have increased 325%; sorghum, 320%; wheat, 146%; rice, 111%; soybean, 93%.

duction of hybrid corn and hybrid sorghum became widespread. In corn the change from open-pollinated varieties to hybrids began in the 1930s; in sorghum the change to hybrids began in the 1950s. Yield increases in the self-pollinated crops were not as spectacular as for corn and sorghum: wheat, 146%; rice, 111%; and soybeans, 93%. But the increases were significant and reflect favorably on the varietal and cultural advancements that were made with these crops during the 50-year period. Rapid advancements in the utilization of fertilizers and pest control chemicals (herbicides, insecticides, fungicides) have been made since the late 1940s. New formulations became available and applications became more precise. It would only be speculation to suggest how much of the yield increases since 1931–1950 were due to varietal improvement and how much resulted from advancements in cultural practices. Suffice it to say that the yield responses from new varieties and improved cultural practices were additive, that one reinforced the other. Alone neither would have been so effective.

WHAT IS PLANT BREEDING?

Plant breeding is the art and the science of changing and improving the heredity of plants. In earlier days the extent of plant breeding as an art and as a science was much disputed. Plant breeding was practiced first when people learned to look for superior plants to harvest for seed; thus selection became the earliest method of plant breeding. The results of those primitive efforts in plant selection no doubt contributed much to the evolutionary development of each of the cultivated crops, however little people may have been conscious of their efforts in the beginning. As human knowledge about plants increased, people were able to select more intelligently. With the discovery of sex in plants, hybridization was added to breeding techniques. Although hybridization was practiced before the time of Mendel, its significance in inheritance was not clearly understood. Thus, Mendel's experiments provided a basis for understanding the mechanism of heredity and how it may be manipulated in the development of improved varieties. A more precise explanation of the heredity mechanism has become possible in recent years with the expansion in our knowledge of biochemical genetics.

The art of plant breeding lies in the ability of the breeder to observe differences that may have economic value in plants of the same species. Before breeders possessed the scientific knowledge that is available today, they relied largely on their skill and judgment in selecting the superior types. Many breeders were good observers, quick to recognize variations among plants of the same species, which could be used as the basis for establishing new varieties. For them, plant breeding was largely an art. Many of the early breeders were amateurs; cultivators who found an off-type plant in their fields or gardeners who found a sport in their beds. Some, like Luther Burbank, were professionals who searched far and wide for unusual plant types that could be developed and exploited commercially.

As the breeders' knowledge of genetics and related plant sciences progressed, plant breeding became less of an art and more of a science. No longer was it necessary for breeders to rely so completely on their skill in finding chance variations with which to establish new varieties. It now became possible to plan and create new types more or less at will. Through scientific knowledge breeders have the background to manipulate and to direct the inheritance of plants. Although skill in the art of selection is important to the modern plant breeder, just as it was to the breeder of the past, now skill alone is not enough. Modern plant breeding is based on a thorough understanding and utilization of genetic principles. It presupposes a knowledge of the botanical characteristics of the species, of plant diseases and their epidemiology, of insect pests that feed upon the different plant species, of physiological factors related to adaptation of plants, and of biochemical characteristics affecting utilization and nutritive value. Without this precise knowledge and background, modern breeders could neither explore nor comprehend the vast range of the breeding problems involved. They could, as did the early breeders, resort only to hit-or-miss methods in breeding, which are costly, inefficient, and time-consuming. It would be like a village blacksmith trying to build a modern automobile with only the crude tools of the blacksmith trade.

THE STRATEGY OF PLANT BREEDING

The strategy of plant breeding is relatively simple. The basic elements of this strategy are

1. to recognize the morphological traits and the physiological and pathological responses of plant species that are important for adaptation, yield, and quality of the crop species;
2. to design techniques that will evaluate the genetic potential for these traits in strains of the appropriate species;
3. to search out sources of genes for the desired traits that may be utilized in a breeding program; and
4. to devise means for combining the genetic potential for these traits into an improved variety or cultivar. How these steps are accomplished will be found in succeeding chapters of this text.

TRAINING FOR THE MODERN PLANT BREEDER

The student may ask, "What do I study to become a plant breeder?" The simplest answer that can be given is, "You need to study plants." But the study of plants encompasses many disciplines. Numerous fields of plant science, as well as other closely related disciplines, are embraced in the training of the skilled plant breeder (Fig. 1.4). It is essential that the modern breeder have training in important areas of knowledge related to plant breeding:

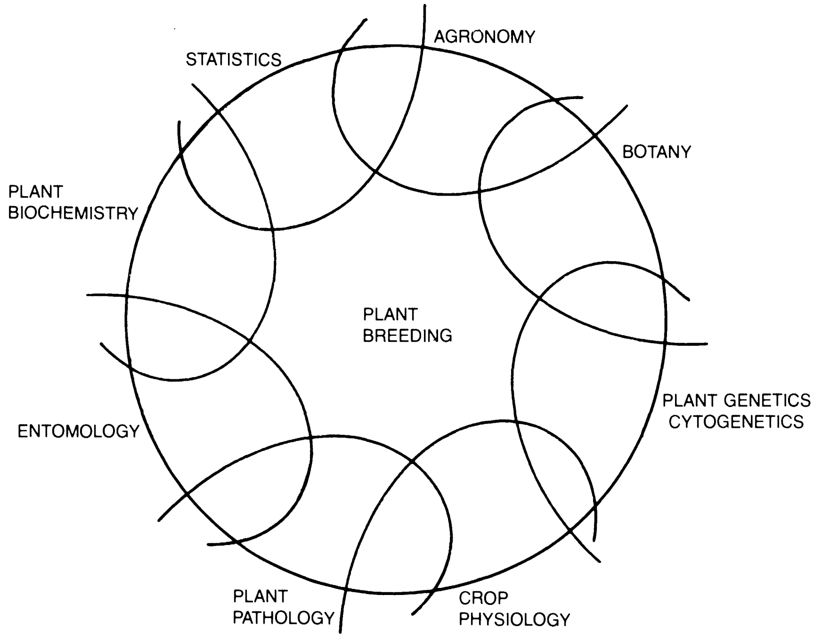

FIG. 1.4. Overlapping relationship of plant breeding with other areas of knowledge. In breeding an improved crop variety, the breeder cooperates with specialists in many fields of plant science and provides them with plant genetic materials for study.

Botany. Plant breeders should be accomplished botanists in order to understand the taxonomy, anatomy, morphology, and reproduction of the plants with which they work.

Genetics and Cytogenetics. The plant breeder needs a thorough understanding of the mechanism of heredity in plants since modern plant-breeding methods are based on a knowledge of genetic principles and chromosome behavior. This knowledge is being extended to the molecular level with advances in biochemical genetics.

Plant Physiology. Variety adaptation is determined by the response of plants to their environment, which includes the effects of heat, cold, drought, and soil nutrient response. The plant breeder strives to make inherent modifications of physiological processes that will enable the plant to function more efficiently.

Plant Pathology. Plant disease reduces crop yields. Host resistance is an important means of combating many plant diseases. Evaluation of the response of the plant genotype to infection by the pathogen is an essential part of breeding for host plant resistance.